Three-pulse phonon (electroacoustic) echo with large relaxation time

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It was observed that stimulated three-pulse phonon echoes of the type $T+\tau$ in crystalline powders of piezoelectrics can be observed at room temperature by applying a third pulse many days after a single application of the first two pulses. The possible nature of this phenomenon is discussed.

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The phenomenon of phonon or electroacoustic echo was observed in[1,2] as a result of investigations in a two-pulse regime, namely, when two radio-frequency electromagnetic pulses were applied to a piezoelectric crystal at the instants of time 0 and τ, a coherent acoustic echo pulse was produced at the instant 2τ and was accompanied by an electromagnetic field. Stimulated three-pulse phonon echo at an instant of time $T+\tau$, where T is the time of application of the third pulse, was observed in[3–6] at helium temperatures.

We have observed and investigated in crystalline piezoelectric powders of bismuth germanate $Bi_{12}GeO_{20}$ and in Rochelle salt a three-pulse echo at $T+\tau$ with a large relaxation time at room temperature.

The investigations were carried out at pulse carrier frequencies from 5 to 70 MHz.[1] We investigated fractions of powders with particle dimensions such that the acoustic-resonance conditions were satisfied at the measurement frequency for most particles. The echo at $T+\tau$ was observed under the condition $\tau < T_2$, where T_2 is the relaxation time determined from the envelope of the two-pulse echo signals at different τ.

Figure 1 shows schematically a three-pulse echo series at the instant $T+\tau$ as a function of T at constant $\tau=\tau_0$, obtained for repeated series of three pulses of equal duration, amplitude, and frequency. At small T, the echo envelope is described approximately by an exponential with a relaxation time T_1 close to T_2, but at $T-\tau_0 \gg T_1$ the echo amplitude tends not to zero but to a certain constant value which exhibits a scatter in different runs of the experiment.

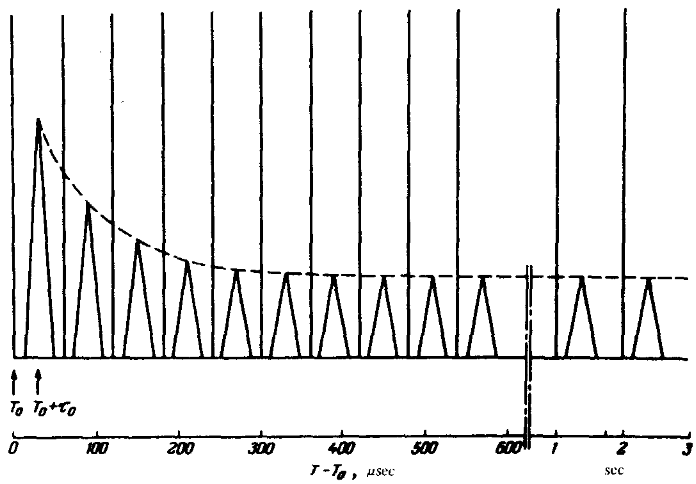

FIG. 1. Schematic representation of a series of echo pulses at $T+\tau$ in bismuth-germanate powder as a function of T at fixed $\tau=\tau_0$ under conditions of repeated series of three sounding pulses. The positions of the vertical lines correspond to the instants of application of the third pulse.

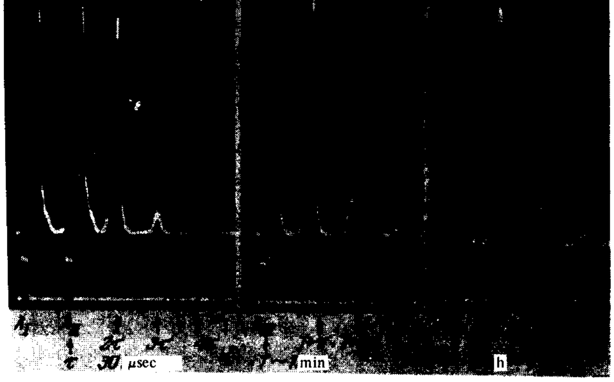

FIG. 2. Runs of two-pulse echoes 2τ, 3τ, and 4τ, obtained under conditions of a repeated pair of pulses (A_{I} and A_{II}) and of three-pulse echoes $T+\tau$, $T+2\tau$, and $T+3\tau$, obtained by applying a third pulse (A_{III}) after a lapse of one minute and 24 hours following the single application of a pair of pulses in bismuth-germanate powder at a temperature $\pm 35\,°C$, at a frequency $\nu_{I}=\nu_{II}=\nu_{III}=28$ MHz, at a repetition period 10 msec for the single pulse and for the pair of pulses, and at a constant receiver gain.

It could be assumed that this scatter was due to incoherence of the sounding pulses, which led to a mutual extinction of the effect in the case of repeated runs. It turned out, actually, that after applying once the first and second pulse and after repeating the third pulse with a repetition period larger than T_2, the magnitude of the echo increased by more than one order of magnitude and became stable. At $T-\tau_0 \gg T_1$, the echo was practically independent of T for several days (Fig. 2). The echo measured in this regime has at large T the following basic properties: The echo amplitude does not vary with the number of repetitions of the third pulse. The echo vanishes when the position of the individual crystallites relative to one another is changed after the termination of the action of the second pulse. Rotation of the ampoul with the powder through $\pm 90°$ about its axis leads to a vanishing of the echo, which returns practically to its previous value once the previous orientation is restored. The amplitude of the echo increases with increasing amplitude of the sounding pulses. When the frequency of the third pulse is varied, the amplitude of the echo goes through a sharp maximum at $\nu_{III}=\nu_{I,II}$, where ν_{III} is the frequency of the third pulse and $\nu_{I,II}$ is the frequency of the first and second pulses.

What is the nature of the investigated echo? At $T+\tau$ the echo can be observed if time-invarient components of the electric field and of the deformation are produced at the instant of action of the second pulse. These components should be modulated in space like $\cos(\mathbf{q}\cdot\mathbf{x})$ ($\mathbf{q}$ is the wave vector of the phonon) in accordance with the values of the phases of the phonons produced by the first pulse at the instant when the second pulse is applied, and should be different from zero at the instant of application of the third pulse. Then the third pulse will produce phonons with $-\mathbf{q}$, which are the ones that produce the echo signal at the instant $T+\tau$ as a result of the in-phasing of the oscillations. One of the possible variants of the interactions that can yield such a constant component of the field or of the deformation is $\cos(\omega t-\mathbf{q}\cdot\mathbf{x})\cos\omega t$, where the first factor is the deformation due to the first pulse and the second factor is the electric field of the second pulse. In the case when electrostriction takes part, this product describes an electric field with a time-invariant component $\cos\mathbf{q}\cdot\mathbf{x}$. The lifetime of this component, however, is equal to the duration of the second pulse, i.e., $\sim 10^{-6}$ sec.

The observation of the echo for many days indicates that the constant component of the field or of the deformation was preserved for a long time after the cessation of the second pulse. The mechanism of such a "pinning" of the charges and deformations may be connected with a redistribution of the defects, including the dislocations. The relative strength of pinning is evidenced by the large relaxation time, and also by the absence of significant changes in the value of the echo when air in the ampoule is ionized by a high-frequency discharge following evacuation with a forevacuum pump, and following irradiation with visible light of low intensity with wavelength corresponding to the pronounced photosensitivity of the bismuth germanate.

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